REPORT #
RRTAC 92-1

Reclamation of Sterilant Affected Sites: A Review of the Issue in Alberta

Heritage Fund

Alberta

LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Alberta's Reclamation Research Program

Regulating surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from Alberta Environment and two Deputy Chairmen from Alberta Forestry, Lands and Wildlife. The Council oversees a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program is provided by Alberta's Heritage Savings Trust Fund, Land Reclamation Program.

To assist with the development and administration of the research program, the Council appointed the inter-departmental Reclamation Research Technical Advisory Committee (RRTAC). The Committee consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, and Environment, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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REPORT #
RRTAC 92-1

Reclamation of

Sterilant Affected Sites:

A Review of the Issue

In Alberta

by

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M. P. Sharma, Alberta Environmental Centre

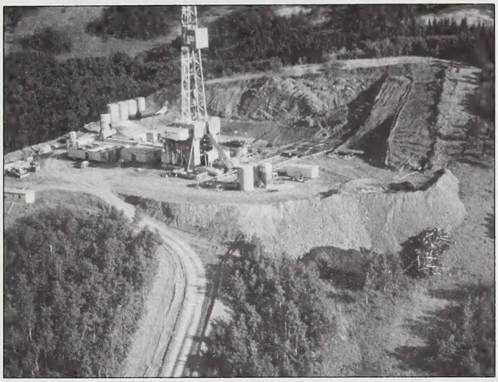
Prepared for

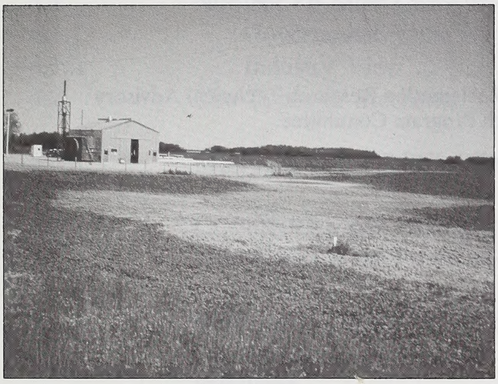
The Oil and Gas Reclamation Research Program
ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

The Reclamation Research Technical Advisory Committee is grateful to
the Alberta Environmental Centre for co-funding this research

1992

Oil and Gas Reclamation Research Program





DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

REVIEWS

This report was reviewed by members of the Reclamation Research Technical Advisory Committee, and the Oil and Gas Reclamation Research Program Committee.

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ABSTRACT

At the request of the Reclamation Research Technical Advisory Committee a project was initiated in June, 1990 with the objectives of assessing the extent of the soil sterilant problem in Alberta and suggesting a research program that would lead to the development of a procedures manual for the reclamation of sterilant affected sites. The research procedure involved the review of literature and extensive discussions with government, industry and research personnel.

It was not possible to estimate the number of sites currently affected by soil sterilants based on the information obtained from industry and government. Most of the estimates were qualitative and they varied greatly depending upon the source of information. However, there may be as many as 61 750 sites in Alberta affected by soil sterilants. This was calculated on the basis of the currently operating oil and gas wells (50 000), those capable of operating (73 000), the total gas plants (500) in the province, and the Green Area permit records from Alberta Environment.

Bromacil and tebuthiuron were the most commonly used soil sterilants in the past and require immediate attention for the reclamation of affected sites. However, the use of atrazine and diuron and two other selective residual herbicides, chlorsulfuron and picloram, has been increasing in the past few years. A description of each herbicide is provided in the report.

The most common method practised by industry for the reclamation of sterilant affected sites involves the use of manure and other organic material such as straw and peat with cultivation. However, this method gives only marginal results and usually takes 3 to 5 years to show results. A second method, that is widely known, but not commonly used, involves the incorporation of activated charcoal, usually in combination with manure. The removal of contaminated soil, by hauling it to another

industrial site, and replacement of the topsoil is also currently employed. This method is not approved by Alberta Environment.

The report outlines methods for assessment of sterilant affected sites including detailed information on soil sampling and methods of herbicide residue detection using chemical analyses and plant bioassays. A list of private laboratories providing herbicide analysis is attached.

A research program related to the reclamation of sterilant affected sites is outlined. The suggested research is based on the concerns of government and industry. It includes the study of: 1) the persistence, leaching, and movement into groundwater of soil sterilants; 2) the development of techniques for reclamation; and 3) the impact of soil sterilants on soil properties.

ACKNOWLEDGEMENTS

This project was supported by the Alberta Heritage Savings Trust Fund Land Reclamation Program, and administered by the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council.

We would like to thank the numerous private and government agencies who provided input and information regarding the soil sterilant issue in Alberta.

We would like to acknowledge the assistance of Ms. Teresa Kupchenko in the preparation of the section containing the descriptions of soil sterilants.

And finally we would like to thank our colleagues who reviewed the manuscript and offered thoughtful criticisms and suggestions.

1. INTRODUCTION

Soil sterilants, residual herbicides that leave treated soil unable to sustain vegetative growth, can persist in soil for many years depending on the chemical, the application rate, the soil type and the climatic conditions. Sterilants are commonly used in Alberta for total vegetation control on oil and gas well sites, plant sites and rights-of-way. They are also frequently applied on other industrial areas such as railways, saw mills, pulp mills, mines, and electrical utility sites.

The reclamation of land affected by soil sterilants in Alberta is governed by the Land Surface Conservation and Reclamation Act of Alberta (Government of Alberta 1984)[1]. The Act requires that soils treated with sterilants be brought back to the level of capability equivalent to that prior to contamination.

According to Maurice (1985) sterilant-treated sites requiring reclamation usually fall into three categories:

1. **Sterilant spills.** These are not common; the sterilant usually remains in the top 15 cm of the soil.
2. **Sterilant escapes from a treated area.** Dallas (1987) reports that off-site movement of sterilants is usually caused by water-induced soil erosion. This can occur when a heavy rainfall follows shortly after sterilant application. Other factors causing sterilant escapes include high application rates of herbicides, application to very sandy soils, poor site contouring and

[1] The 'Alberta Environmental Protection and Enhancement Act' (June 1992) has replaced the Land Surface Conservation and Reclamation Act of Alberta.

improper control of water run-off. Occasionally, salt water spills have washed sterilants off-site resulting in a compounded problem of sterilant and salt contamination. Dallas (1987) also reported that off-site soil contamination by sterilants is decreasing. This was substantiated by many government and industry personnel. They feel that the decrease is probably a result of reduced sterilant use and more controlled application of products. Several companies are changing their vegetation control programs to avoid using sterilants. When sterilants are used, the trend is to limit application to restricted areas and to leave a buffer zone at the site perimeter.

3. **Decommissioned sites.** These sites are the most common. In this situation, a site that was treated previously with sterilants no longer requires long term vegetation control and must be reclaimed. Usually applications of high rates of several sterilants have been used over many years. Often, the sterilants can be found to a depth of 45 cm or more, and therefore extensive reclamation is required. Decommissioned sites may also be contaminated by salts and hydrocarbons. Soil compaction and mixing of soil horizons during site construction and maintenance may also compound the problem. The magnitude of this problem has not been described previously (Dallas 1987).

At the request of the Reclamation Research Technical Advisory Committee (RRTAC), a project was initiated to assess the issue of soil sterilants on industrial sites in Alberta.

2. OBJECTIVES

The objective of this project was to determine the scope of the soil sterilant problem in Alberta and suggest a research program that would ultimately lead to the development of a procedures manual for the reclamation of sterilant affected sites.

3. TERMS OF REFERENCE

1. Identify and describe through a review of the literature and through interviews with government, industry and research personnel:
   i. The extent of sterilant use in Alberta, including an estimate of the number of sites requiring reclamation and the types of chemicals used in the past, currently in use and those scheduled for future use.
   ii. Methods for measuring the type and amount of sterilant on an affected site in Alberta, including soil sampling, soil analysis, and plant bioassays.
   iii. Common methods for reclaiming sterilant affected sites in Alberta.
   iv. Concerns of government and industry related to the reclamation of these sites.
2. Develop a research program for the reclamation of sterilant affected sites in Alberta on the basis of the information obtained.

4. SCOPE OF THE STERILANT ISSUE IN ALBERTA

The statements presented in this section of the report have resulted from a series of interviews (see Section 8. Personal Communication), and are not attributed to specific individuals.

4.1 NUMBER OF SITES CURRENTLY AFFECTED BY STERILANTS

The estimates varied according to the source within the government and within the industry.

4.1.1 Government View

Among government personnel from various agencies and departments, the estimate of affected areas varies. Most Energy Resources Conservation Board (ERCB) officers are aware that some sites are affected by soil sterilants, but many do not feel it is a serious issue at this time and have few concerns related to the reclamation of these sites. This is probably because the Reclamation Officers of the Land Conservation and Reclamation Council are responsible for the certification of oil and gas sites, and in most cases the ERCB has no record of any problems.

Most Alberta Forest Service personnel do not feel that the sterilant issue is significant; they are not aware of any reclamation of sterilant affected sites in their areas. This was surprising considering the number of sites in the Green Area (Figure 1) that are treated with soil sterilants each year (Table 1). The Green Area is the forested area of the province. The White Area comprises the agricultural areas of the province. The apparent lack of sterilant affected sites in the Green Area may be because sterilant use in this area is

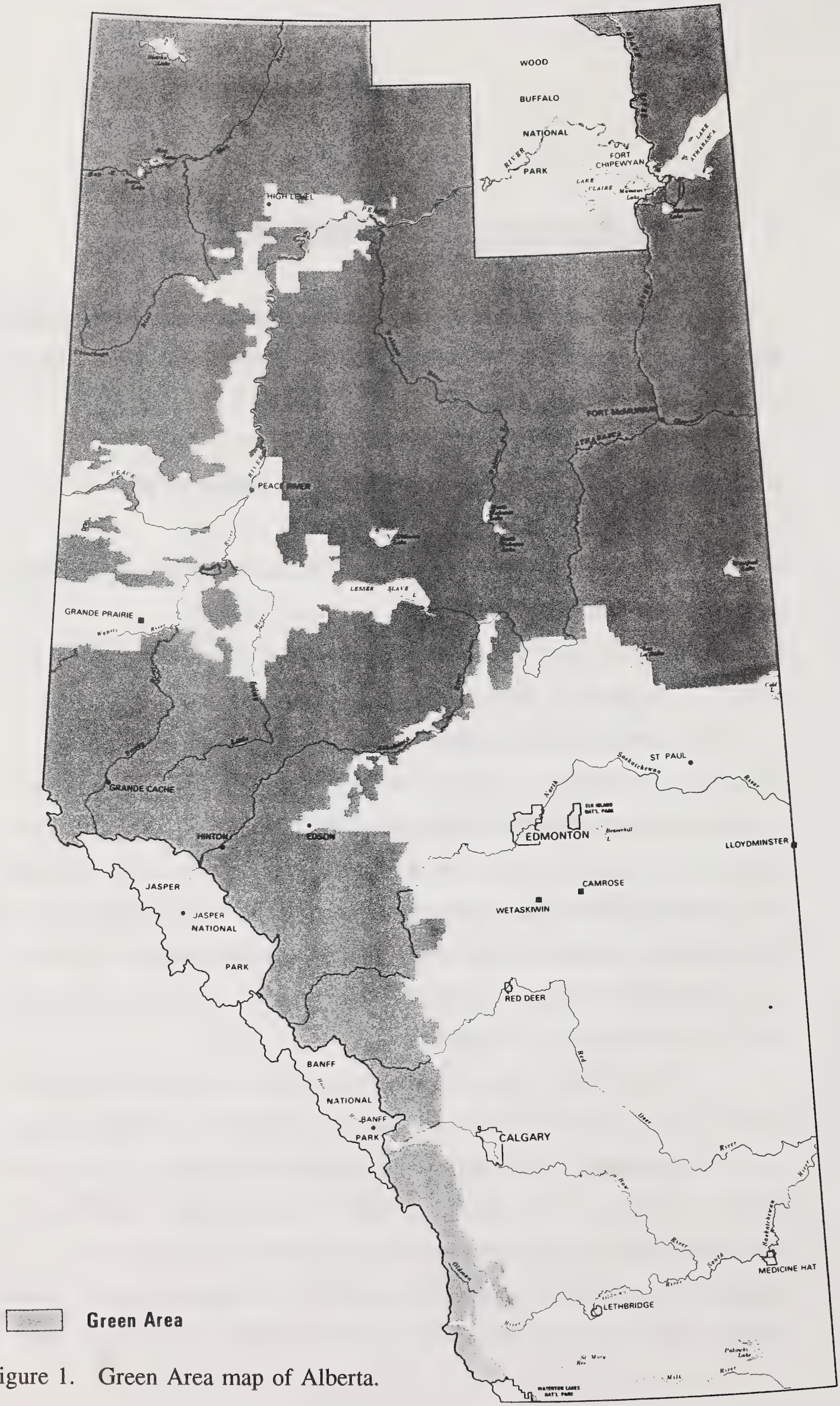

Figure 1. Green Area map of Alberta.

relatively new, and there is little decommissioning occurring in the Green Area at this time.

Reclamation Officers of the Land Conservation and Reclamation Council are directly involved with decommissioned sites and have a close association with the sterilant issue. Generally, they think that the number of the sites currently affected by sterilants is significant, and the significance varies depending on the age of the oil and gas fields. The older fields are more severely affected because more of these sites were treated with sterilants.

In order to put a quantitative estimate on the number of sites where sterilants have been used in Alberta it is important to note that there are close to 50 000 operating oil and gas wells, plus over 73 000 wells capable of being operated, approximately 500 operating gas plants, and more than 200 000 km of pipelines (Personal communication, Roger Creasey, Energy Resources Conservation Board). If only 50% of oil and gas wells have been treated with soil sterilants, 61 750 sites have been affected. This excludes application of sterilants on pipelines, saw mills, pulp mills, mines, and electric utility sites. Sterilant application records from one vegetation management company over the 1990 growing season confirm that this is a conservative estimate.

The use of soil sterilants in the Green Area of Alberta can be estimated accurately. Alberta Environment requires that all herbicide applications in the Green Area be done under permit. A summary of the results yields a quantitative estimate of the number of sites that are currently affected by soil sterilants (Table 1).

Approximately 4000 sites were treated with sterilants between 1986 and 1990 in the Green Area alone. But, two limitations to these data should be noted: first, the Green Area probably represents less than 40% of the total number of oil and gas sites in the province; second, a small percent of the

Table 1. Number of oil and gas sites treated with soil sterilants in the Green Area of Alberta between 1986 and 1990.

Particulars	Year 1986	1987	1988	1989	1990	Total
Total Sites Treated[a]	501	488	1066	2281	1260	5596
Sites Treated With Sterilants[b]	407	387	757	1748	709	4008
Breakdown of Herbicides Usage[c]:						
Bromacil	23	65	238	109	94	529
Tebuthiuron	50	7	24	0	40	121
Atrazine	269	288	491	1521	444	3013
Diuron	119	12	155	91	333	710
Chlorsulfuron[d]	169	257	494	1367	610	2897
Picloram[e]	37	71	120	135	175	538

[a] Sites treated with sterilants and non-residual herbicides.

[b] Sites treated with sterilants only.

[c] Some sites were treated with more than one sterilant.

[d] Chlorsulfuron and picloram are long term residual broadleaf herbicides when applied at industrial use rates.

Source: Alberta Environment, Pesticide Management Branch.

5600 sites treated will represent retreatment of the same location because on average sterilants are applied to a site once every three years. A comparison of total treated sites to sterilant treated sites (Figure 2) shows a consistent use of sterilants over this five year period with an average of 72% of total sites treated with sterilant. However, it should be noted that in 1990 the number of sites treated with sterilants decreased to 56% of the total sites treated with herbicides. There was a doubling of the number of sites treated with herbicides (and sterilants) in 1988, and again in 1989 (Figure 2), corresponding to a procedural change in the permitting process for applicators in the Green Area. The permits changed from individual to company permits, and a one hectare limit per site was lifted.

The results obtained in the Green Area can be considered to reflect the use of soil sterilants in the whole province. Extrapolation from the Green Area may be conservative because the permitting process for herbicide application in this area is stricter than in the rest of the province.

4.1.2 Industry View

The interviews revealed that some companies in the oil and gas industry had serious problems with sterilant affected sites and others felt that they were unaffected by soil sterilants, although they had used soil sterilants and in some cases were still using them. This divergence can be attributed to several factors. The companies that felt they did not have a problem with soil sterilants viewed off-site movement as the major cause of concern. These companies apparently were not experiencing any off-site movement. Better training of herbicide applicators and the wide-spread use of licensed applicators has reduced the problem of off-site movement overall. In addition, these companies were not currently involved in decommissioning sites treated with

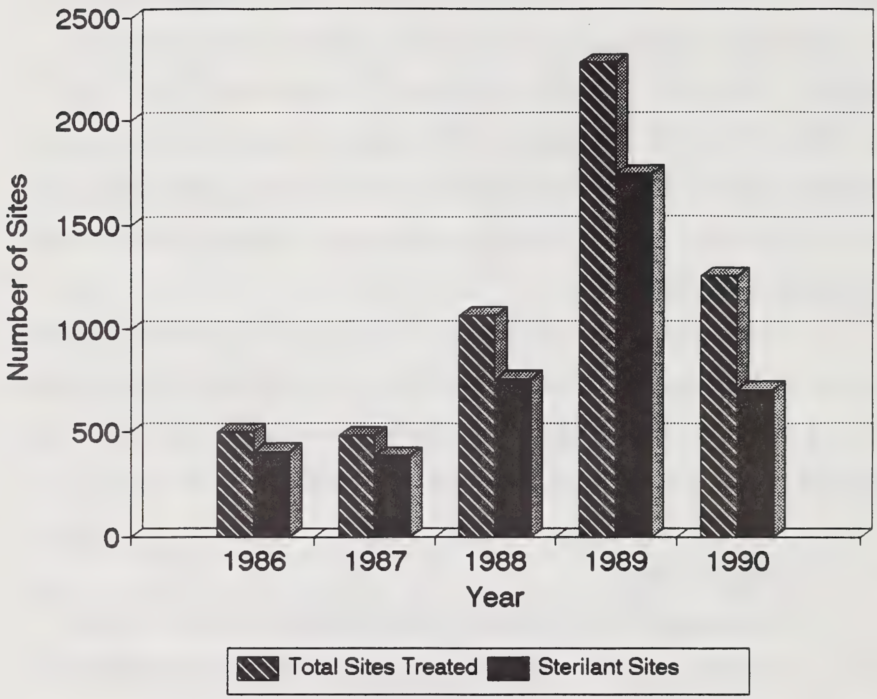

Figure 2. Use of soil sterilants in Alberta in the Green Area - 1986 to 1990.

sterilants. Until decommissioning proceeds the problem of soil sterilant contamination is not always apparent. The life span of an industrial site is finite, and this must be kept in mind when planning vegetation control measures.

Some companies which have off-site movement of soil sterilants and are undertaking site decommissioning have made recent policy changes discouraging or banning the use of sterilants on their facilities. They now anticipate a steady decrease in soil sterilant problems. However, it must be kept in mind that there is a lag period between the old and the new policies. The sterilant residues will have to be dealt with for some time because of the persistence of sterilants, the multiple applications and combinations of sterilants that were applied. As well, it is difficult in large companies to ensure that everyone involved in vegetation management is avoiding the use of soil sterilants. In large companies weed control is often looked after by area supervisors and foremen and, ultimately, they make the decision whether or not to use particular products. Many oil and gas companies have different divisions, and each division may be following different polices.

4.2 THE TYPES OF STERILANTS IN USE

The most commonly used sterilants in the Green Area are atrazine, diuron, bromacil, and tebuthiuron (see Appendix 9.1 for a description). Figures 3 and 4 show the fluctuation in the use of all four sterilants from 1986 to 1990 in the Green Area. Use of bromacil and diuron ranges from about 5% to 25% of the total sites treated. Tebuthiuron shows consistently low usage ranging from 10% in 1986 to 0% in 1989. Atrazine, the most commonly used sterilant in the Green Area, fluctuates from 35% to 67% of total sterilant use averaging about 54%.

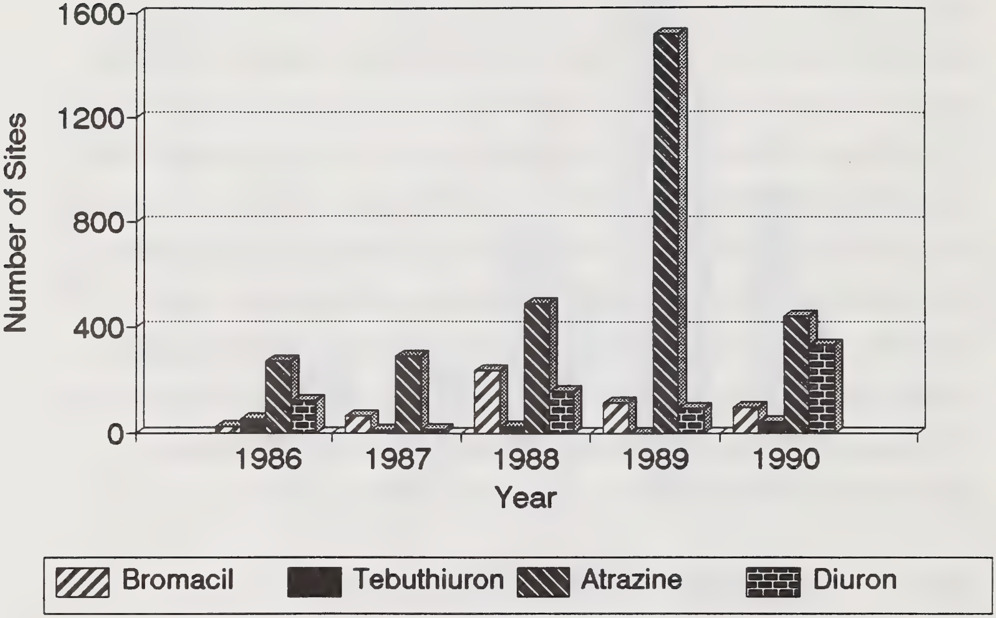

Figure 3. Number of sites in the Green Area of Alberta treated with specific soil sterilants between 1986 and 1990.

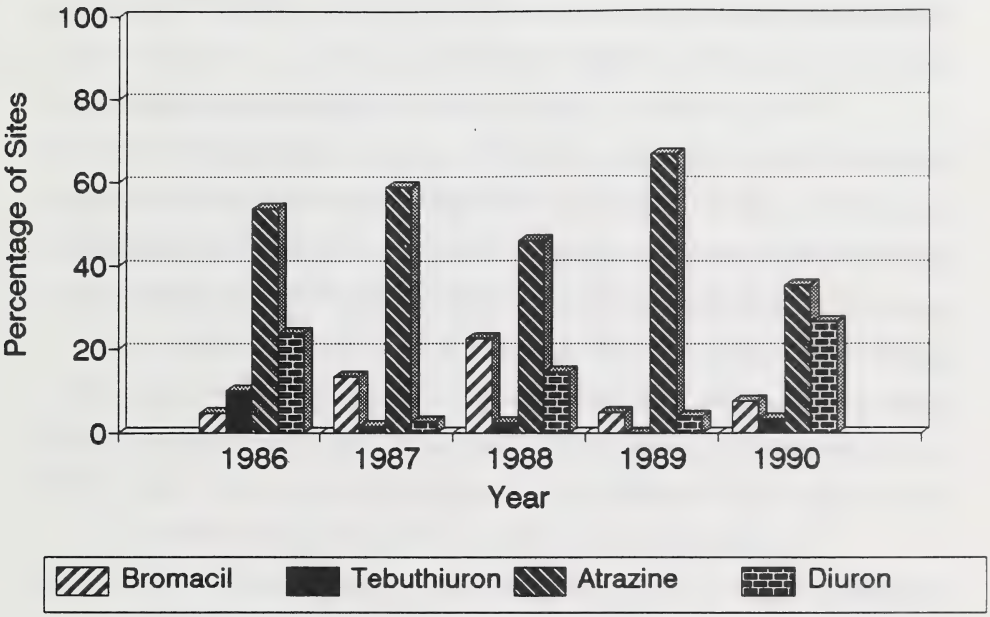

Figure 4. Use of specific soil sterilants (% of total sites) in the Green Area of Alberta between 1986 and 1990.

Two selective herbicides, chlorsulfuron and picloram are residual and used widely (Table 1). They are active at extremely low concentrations and may pose a problem by restricting the growth of broadleaf plants. Chlorsulfuron use has increased in the Green Area over the last five years. In 1986 it represented only 34% of all herbicide usage; in 1989 that increased to 60%. Chlorsulfuron was registered as an industrial herbicide in 1986. Picloram was applied to an average of 10% of all sites treated with herbicides in the Green Area between 1986 and 1990.

Dupont Canada Inc. indicated that acreage in Alberta receiving long-term residual herbicides, mainly oil leases, plants, pipeline and utility sites has declined by about 15% between 1987 and 1989. But there were more hectares treated with Dupont's products in 1990 than in 1987, even though the amount of sterilants used on these kinds of sites did not change. More applications of hexazinone and diuron at low rates and an increased use of products not requiring a licensed applicator such as Calmix® (bromacil) pellets may be the reason for more acreage. The use of traditionally popular products, such as Hyvar XL® (bromacil) has dropped by almost 50% from 1986 to 1990.

Atrazine appears to be the most commonly applied sterilant followed by diuron and bromacil. Current use of tebuthiuron is minimal. This applies only to the Green Area, however, sterilant use in all of Alberta is probably similar.

Bromacil and tebuthiuron were consistently identified in interviews as the major products used on reclamation sites. Atrazine and diuron were seldom mentioned as a problem. There seems to have been a shift in sterilant use. Bromacil and tebuthiuron were used much more extensively in the past; atrazine is used more now and may be the contaminant of concern on future reclamation sites. The widespread use of chlorsulfuron may cause it to be

found on decommissioned sites in the future. Bromacil and diuron may be used again in large amounts because of their new formulation as a dry flowable mixture (Krovar®). Diuron is desirable in this mixture because it adsorbs readily to the soil and therefore does not move by leaching (Ali 1991). Applicators use lower rates of a mixture of sterilants to reduce the potential for off-target movement. Premixed products like Krovar® will become popular as applicators become aware of the lack of registered tank mixes. Diuron alone is also formulated as a dry flowable (Karmex®). Dry flowable formulations are convenient products for the applicator.

It is unlikely that there will be many new sterilants developed in the future. The high cost of herbicide research and development has reduced the numbers of new registrations. The new registrations will probably be tank mixtures of products already in existence.

5. METHODS OF RECLAIMING STERILANT AFFECTED SITES

In Alberta there are a number of methods used to reclaim sterilant affected sites. The most common method incorporates manure and other organic materials, such as straw and peat, with fertilizer. However, this method yields marginal results, and can take several years or more to be effective. Furthermore, success could be just a result of sterilant dilution, normal dissipation, and the effect of the manure and fertilizer on the soil itself.

The incorporation of activated charcoal, usually in combination with manure, or straw, and sometimes fertilizer, is used by larger companies and has provided satisfactory results. The companies practising this method use either their own research or rely on recommendation in the Field Manual for Rehabilitating Soils Affected by Residual Herbicides, Third Edition (IVMAA 1987) to select the rates and methods of incorporation of activated charcoal. The companies that have not used charcoal as a reclamation method felt that it was either too expensive, or they had reservations about the long term effectiveness of activated charcoal.

Another method of reclamation is the excavation of contaminated soil, deposition in another industrial site, and replacement of topsoil. This method has been successful, but it is not practical. Eventually the contaminated soil must be managed. Alberta Environment recommends that the contaminated soil should not be removed (Personal communication, Jock McIntosh, Alberta Environment). If it is removed, it must be disposed of in an approved landfill (Personal communication, Tony Fernandes, Alberta Environment).

Some companies do not employ any reclamation measures and rely on natural processes to break down the sterilants in soil. Other companies use only tillage before they attempt crop establishment. Generally, these low input methods are not very successful.

Appendix 9.2 of this report outlines steps that can be used to assess sterilant affected sites in a reclamation program.

6. CONCERNS OF GOVERNMENT AND INDUSTRY RELATED TO THE RECLAMATION OF STERILANT AFFECTED SITES

The most common concerns based on personal interviews (Section 9) are identified below in order of priority.

1. Leaching and persistence of sterilants (this concern came up in over half of the interviews):
   How long does each of the sterilants persist in Alberta soils under our climatic conditions? How deep in the soil profile does each of the sterilants leach?
2. Use of activated charcoal (the first three questions came up in half of the interviews):
   - i. How permanent is the adsorption of the sterilant on to the charcoal?
   - ii. Does activated charcoal work under all soil conditions?
   - iii. What types of charcoal work best? There seems to be some discrepancy over the types of charcoal, particularly the mesh size.
   - iv. Does it make a difference whether the charcoal is applied as a wet slurry or a dry powder?
   - v. How well should the charcoal be mixed in soil?
   - vi. Does activated charcoal absorb water and maintain moisture content in soil? It seems to make a wet site wetter.
   - vii. Are sterilants adsorbed on activated charcoal degraded by microorganisms?

3. Use of other amendments (these questions came up in about half of the interviews):
   i. Are there amendments other than activated charcoal and manure for sterilant reclamation?
   ii. What amendments work on what soils under what conditions? More field experiments are needed.
   iii. Is manure effective?
   iv. Is the application of activated charcoal and manure together more effective than either applied alone?
4. Crops tolerant to soil sterilants:
   i. What is the most tolerant crop species and what factors influence this?
   ii. How sensitive are different crops to sterilants?
   iii. What is the effect of crop growth stage on sensitivity to sterilants?
5. Relationship between soil microorganisms and soil sterilants:
   i. How do sterilants affect soil microorganisms?
   ii. What microorganisms are effective in degrading the sterilant, and how can they be increased in affected soils?
6. Analytical methods for soil sterilant:

   Sterilant analysis in the laboratories must be standardized to provide consistent results. There are some gross differences in laboratory analysis between labs. This can be a problem when selecting ratios for amendments and sterilants for reclamation.

7. Effect of soil sterilants on soil physical and chemical properties:
   i. Do sterilants affect or alter the physical properties of the soil, and if they do, in what way?
   ii. Is there an effect of sterilants on soil pH, humus and organic matter of the soil?
8. Miscellaneous:
   i. How can soils affected by sterilants to greater than 15 cm be reclaimed?
   ii. How can soil affected by more than one contaminant, for example, brine spills and residual herbicides be reclaimed.
   iii. Are different reclamation techniques needed for recently treated soil and soil that had sterilant applied years ago.
   iv. Are soil sterilants introduced into the food chain?
   v. What are the alternatives to using sterilants?
   vi. How can sterilants be used so that reclamation is not needed?
   vii. Is the legislation on the use of herbicides strict enough with respect to where and when sterilants are used? It may be desirable to look at restricting the use of these products rather than relying on self regulation.

7. RESEARCH PROGRAM OUTLINE

Based on our interviews, the following projects are proposed for detailed investigation. These projects provide an overall outline and are not comprehensive proposals for purposes of soliciting funds from RRTAC or other agencies. Detailed proposals should be developed for each project.

7.1 PERSISTENCE, LEACHING AND MOVEMENT INTO GROUNDWATER OF SOIL STERILANTS

The behaviour and fate of residual herbicides, including sterilants in soil, is governed mainly by the types of chemicals, the rate and frequency of their use, and the soil and climatic conditions. Soil sterilants can persist in soil for several years. Studies conducted under field and laboratory conditions on soil sterilant behaviour and fate in soil are needed.

7.1.1 Field Studies

Experiments should be conducted at several locations representing various soil and climatic conditions throughout Alberta. Bromacil, tebuthiuron, atrazine and diuron should be investigated at several rates for leaching to various depths in soil, movement in surface water and groundwater, and persistence in soil. Residues should be analyzed by bioassay and chemical analysis.

7.1.2 Laboratory Studies

The persistence and leaching (in soil columns) of each soil sterilant should be investigated in Alberta soils collected from locations in the field study. The effect of soil temperature, soil moisture, and soil type should be studied.

The information generated from the field and laboratory studies can be used to predict the persistence (half-life) and leaching of residual herbicides in soil. The predictions will probably be based on kinetic rate equations and will quantify the relationship between soil sterilant concentrations in soil as a function of soil variables, such as texture, pH, moisture, temperature, and the time elapsed since the last herbicide application.

7.2 DEVELOPMENT OF TECHNIQUES FOR RECLAMATION

Amendments other than manure and activated charcoal should be tested, coupled with differences in season (spring versus fall) of application, the interval between amendment application and seeding, the methods of amendment incorporation, and the number of cultivations needed for complete incorporation. Laboratory studies should also be conducted to select the best amendments and agronomic techniques. Then the best reclamation options need to be field tested on sites affected with bromacil, tebuthiuron, atrazine, and diuron at several locations throughout the province, representing various soil and climatic conditions.

7.3 IMPACT OF SOIL STERILANTS ON SOIL CHARACTERISTICS

Concerns were expressed about the effect of soil sterilants on soil microorganisms, and soil physical and chemical properties. Field and/or laboratory studies should be conducted to investigate sterilant effects on soil

microbial populations, microbial activity (by measuring evolution of CO_2 and enzyme activity), organic matter content, soil pH, bulk density and aggregate size.

8. PERSONAL COMMUNICATIONS

8.1 ALBERTA ENVIRONMENT

8.1.1 Land Conservation and Reclamation Council

Calgary
- Bruce Patterson
- Michael Melnyk

Camrose
- Bill Black
- Bus Terry

Edmonton
- Arnold Janz

Edson
- Doug Beddome (transferred to Calgary)

Grande Prairie
- Richard Anderson

Hanna
- Eugene Harrison
- Ken Wells

Lethbridge
- Steve Demkiw

Medicine Hat
- Blair McNeely

Peace River
- Allan Malcolm

Red Deer
- Bill Fisher

St. Paul
- Chris Predy

Stony Plain
- Rick Ostertag
- Ross Pituka

Wainwright
- Jim North
- Mike Smith

8.1.2 Environmental Protection Services

Edmonton
- Tony Fernandes
- Mark Kohlruss
- Neil Wandler
- Jock McIntosh

8.1.3 Alberta Environmental Centre

- Richard Coleman
- Richard Johnson
- Dave McNabb
- Paul Yeung

8.2 ENERGY RESOURCES CONSERVATION BOARD

Bonnyville
- Guy Hurtubise

Calgary
- Roger Creasey
- Dave Hill

Drayton Valley
- Dan Sarnecki

Edmonton
- Harvey Sondergard
- Brent Harrison

Grande Prairie
- Ed May
- Brian Olson

Medicine Hat
- Marvin McNeil

Red Deer
- Terry Christenson

Wainwright
- David DeGagne

8.3 FORESTRY, LANDS AND WILDLIFE

8.3.1 Alberta Forest Service

Edmonton
 Sam Takyi
Athabasca Forest
 Jerry Kress
Bow/Crow Forest
 George Benoit
Edson Forest
 Dennis Cox
Footner Lake Forest
 Vern Neil
Grande Prairie Forest
 Ken Glover
 Kevin Dewhurst
Lac La Biche Forest
 Dan Slaught
Peace River Forest
 Gordon Krassman
Rocky/Clearwater Forest
 Murray Doherty
Slave Lake Forest
 Ian Woodby
Whitecourt Forest
 Ed Dechant

8.3.2 Public Lands Division

David Lloyd

8.4 ALBERTA AGRICULTURE

8.4.1 Plant Industry Division

Denise Maurice

8.5 INDUSTRY

AEC Pipeline
  Glen MacIntosh
Alberta Energy Company Ltd.
  Craig Etty
Alberta Power Ltd.
  Jivan Kayande
  Brian Harris
Amoco Canada Petroleum Company Ltd.
  Ron Findlay
Atcor Resources Ltd.
  Jim Munroe
Bow Valley
  Gary Mott
B.P. Canada Ltd.
  Rob Staniland
Canadian Jorex Ltd
  John Fraser
Canadian Petroleum Association
  Ian Scott
Chevron Canada Resources Limited
  Glen Younghusband
CN Rail
  Doug Wong
  Brian Pimblette
Esso Resources Canada
  Dave Slade
  Neil Drumond
  Mike Locke
Home Oil Co. Ltd.
  Jim Wurzer
Husky Oil Marketing Company
  David McCoy
Interprovincial Pipeline (IPL) Company
  John Hayes
  Tim Bossenberry
Mobil Oil Canada
  Dave Sitar
  Herb Demars

Norstar Energy Corp.
 Darell Seib
Northwestern Utilities Ltd.
 Dale Standard
 Graham Morris
 Leonard Josephison
Nova Corporation of Alberta
 Steff Stephansson
 Al Fedkenheuer
Petro Canada Inc.
 Wayne Weibe
Shell Canada Products Ltd.
 Doug Mead
Syncrude Canada Limited
 Tony Dai
TransAlta Utilities Corporation
 John Hastie
 Sieg Guggenmoos
 Brad Wright

8.6 HERBICIDE MANUFACTURERS

Dow Elanco Canada Inc.
 Brian Rosentreter
Dupont Canada Inc.
 Wayne Spurrill

8.7 RECLAMATION COMPANIES

Diamond C Consultants
 Clarence Harrison
Western Oilfield Environmental Services Ltd.
 Al Scheibner
 Dave Headdon

8.8 VEGETATION CONTROL COMPANIES

Ace Vegetation Control Service Ltd.
    Ian Mcdonald

8.9 ANALYTICAL LABORATORIES

AGAT Laboratories
    Tony Smith
    Debbie Winslow
Chemex Labs Alberta Inc.
    Bob Faye
Core Laboratories
    Bob Swingle
Enviro-Test Laboratories
    Dennis Erickson
Norwest Labs
    Erv Callin

9. APPENDICES

9.1 DESCRIPTION OF SOIL STERILANTS AND OTHER RESIDUAL HERBICIDES

9.1.1 Atrazine (Triazine family)

6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine

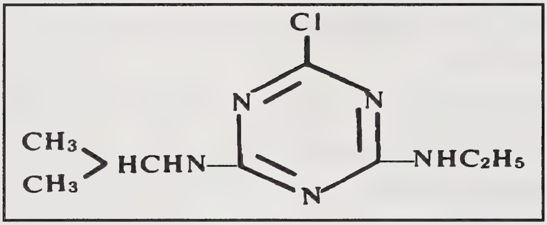

Figure 5. Chemical structure of the atrazine molecule.

Trade Names: AATREX® Liquid 480g/L
AATREX® Nine-O 90% granular
ATRAZINE 500 500g/L flowable
ATRAZINE 90W 90% wettable powder

Atrazine is a commonly used selective herbicide for weed control in agricultural production (Ali 1991). At higher rates, it is a nonselective, foliar- and soil-applied herbicide used for general vegetation control on non-crop land (WSSA 1989).

Leaching and soil movement may occur on sandy soils as a result of heavy rainfall (Ali 1991), but atrazine is generally not very mobile and tends to remain in the top 30 cm of soil (Radermacher and Leadbetter 1986).

Atrazine reversibly adsorbs on soil particles, more so on organic and clay soils than low clay and low organic matter content soils (WSSA

1989). This adsorption can be readily reversed depending on the temperature, soil moisture, and soil pH (WSSA 1989). As well, activated carbon will adsorb and deactivate atrazine in soil (Radermacher and Leadbetter 1986).

The half life of atrazine is estimated to be two months at 30°C and six months at 15°C (Radermacher and Leadbetter 1986). When conditions are not favourable for maximum chemical or biological activity, atrazine may persist in the soil for longer than one year (WSSA 1989). Atrazine degradation occurs through an adsorption catalysed hydrolysis reaction (Radermacher and Leadbetter 1986). The degradation rate of atrazine increases with the organic matter content, moisture content, and temperature of soil; degradation increases as pH decreases (Radermacher and Leadbetter 1986). Microbial activity is largely responsible for atrazine degradation in soil; many soil microbes can use it as a source of energy and nitrogen (WSSA 1989). Soil amendments, such as glucose, nutrient broths, and decomposable crop residues that increase microbial activity, will enhance atrazine degradation (Radermacher and Leadbetter 1986).

9.1.2 Bromacil (Uracil family)

5-bromo-6-methyl-3-(1-methyl-propyl)-2,4(1*H*,3*H*) pyrimidinedione

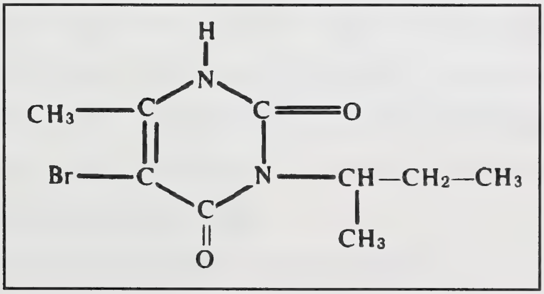

Figure 6. Chemical structure of the bromacil molecule.

Trade Names: CALMIX 3% bromacil/5% 2,4-D pellets
HYVAR®-X 80% wettable powder
HYVAR®-XL 240 g/L miscible liquid
KROVAR® I 40% bromacil/40% diuron wettable powder
KROVAR® II 53% bromacil/27% diuron wettable powder
BOROCIL™ (mixture of bromacil + borax)
HYBOR-D 2% bromacil/5% 2,4-D granular
BROMAX 4L (4 lb/gal)
BROMAX 4G (4% granule)

Bromacil is a nonselective herbicide used on non-crop land for control of a wide range of annual and perennial grasses, broadleaf weeds and certain woody species (WSSA 1989).

Bromacil leaches readily and will move into the root zone, because of its high solubility and mobility (Sharma 1986). Bromacil is much less likely to adsorb to soil colloids than many other herbicides (WSSA 1989).

The half life of bromacil is 4.5 months at 30°C and seven months at 15°C (WSSA 1989). As a sterilant, it may persist in the soil for one or more years (Sharma 1986). Degradation by soil microbes is the main mode of disappearance from soil (WSSA 1989).

9.1.3 Chlorsulfuron (Sulfonylurea family)

2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino] carbonyl]benzenesulfonamide

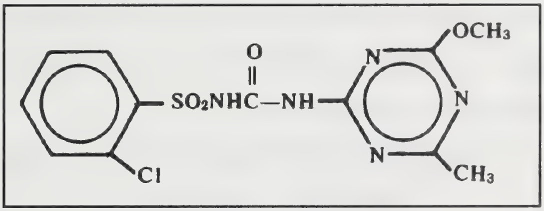

Figure 7. Chemical structure of the chlorsulfuron molecule.

Trade Names: GLEAN® 75% dry flowable

GLEAN® 20DF 20% dry flowable

Chlorsulfuron is used both as an agricultural and an industrial herbicide to control annual and perennial broadleaved weeds and brush species (Sharma 1986).

Leaching and movement of chlorsulfuron in soil is related to the movement of soil water and soil pH (WSSA 1989). Fine particles, soil organic matter, and neutral to acidic conditions will restrict soil movement of the herbicide (Ali 1991). Adsorption of chlorsulfuron to clay particles is low, but adsorption to organic matter is slightly higher (WSSA 1989).

Field conditions cause a great variation in the adsorption and degradation of chlorsulfuron. Reports of half-life vary from 12 days to 168 days depending on the soil conditions and the study (Walker et al., 1989; Thirunarayanan et al., 1985). When soil temperatures increase there is a reduction in the half life (WSSA 1989).

Trace levels of chlorsulfuron residue in the soil can cause injury to sensitive plants several years after application (Sharma 1986). Soil microbes

break down the chlorsulfuron molecules by hydrolysis into lower molecular weight compounds (WSSA 1989). Hydrolysis is accelerated by lower soil pH levels.

9.1.4 <u>Diuron</u> (Urea family)

N'-(3,4-dichlorophenyl)-*N*,*N*-dimethylurea

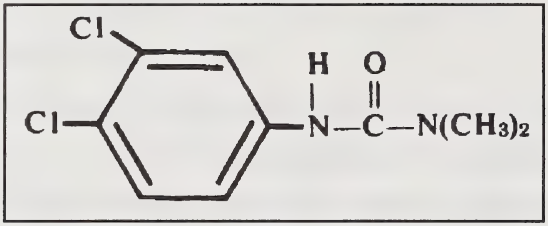

Figure 8. Chemical structure of the diuron molecule.

Trade Names: KARMEX® 80% dry flowable
KROVAR® I 40% diuron/40% bromacil wettable powder
KROVAR® II 27% diuron/53% bromacil wettable powder
VELPAR® K-4 46.8% diuron/13.2% hexazinone wettable powder

Diuron is used for vegetation control in irrigation and drainage ditches, and as a nonselective weed killer in non-crop land (Sharma 1986). Diuron is leached very slowly and is usually confined to the top 15 cm of soil, depending on the soil type (WSSA 1989).

Diuron readily adsorbs to soil particles (Sharma 1986). Clay and organic matter will increase the adsorption rate of diuron (WSSA 1989). As well, clays with a high exchange capacity will adsorb more diuron than those with low exchange capacity.

The half-life of diruon has been reported between 52 and 65 weeks. When used as a soil sterilant, diuron will persist for several years (Sharma 1986). Microbial degradation is mainly responsible for its disappearance from the soil, and the addition of readily decomposable organic matter to soil will encourage the degradation process (Radermacher and Leadbetter 1986).

9.1.5 Picloram (Pyridinecarboxylic Acid family)

4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid

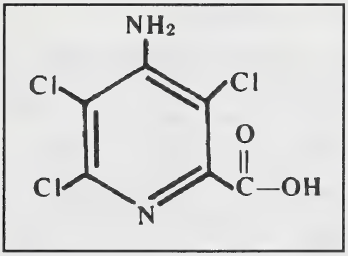

Figure 9. Chemical structure of the picloram molecule.

Trade Names: TORDON K and TORDON 22K 0.24 kg/L picloram as K salt
TORDON 101 Mixture 0.06 kg/L picloram + 0.24 kg/L 2,4-D as amine salts

Picloram is a broad-spectrum, selective herbicide used to control most annual and perennial broadleaved weeds and woody plants on crop and non-crop land (WSSA 1989).

Picloram will move with soil water, because it is very soluble in water (WSSA 1989). Mobility is also related to soil pH, and residues may be found down to a depth of 90 cm after 1 year (Radermacher and Leadbetter 1986). A heavy rain can carry picloram away from the site or past the root zone of target plants, especially in sandy soils (Ali 1991).

The half-life of picloram has been reported between 78 and 104 weeks (NRCC 1974). Picloram does not strongly adsorb to soil particles (Sharma 1986), although organic matter and some clays do show a bonding capacity (WSSA 1989). Microbial degradation of picloram is slow (Sharma 1986). Forty percent can remain in the soil one year after application, and often picloram will persist for two to five years. Soil conditions that favour microbial activity will also facilitate the degradation of picloram (WSSA 1989).

9.1.6 Tebuthiuron (Urea family)

N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-y1]-*N,N'*-dimethylurea

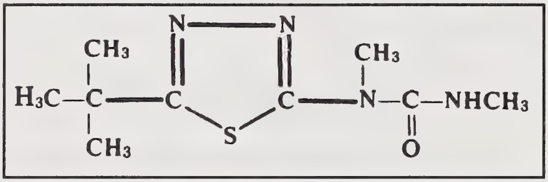

Figure 10. Chemical structure of the tebuthiuron molecule.

Trade Names: SPIKE 20P 20% pellet
SPIKE 40P 40% pellet
SPIKE Dry Flowable
SPIKE 80W 80% wettable powder
SPIKE 5G 5% granules
HERBEC 20P 20% pellet

Tebuthiuron is a nonselective soil sterilant used on non-crop land for general vegetation control (WSSA 1989).

Tebuthiuron does not readily leach into the root zone without rain (Ali 1991). It is adsorbed strongly on soil particles (Sharma 1986) and thus stays evenly distributed in the top 30 to 60 cm of soil (WSSA 1989). The

adsorption rate is related to the level of organic matter and clay in the soil and it varies inversely with soil pH (Radermacher and Leadbetter 1986).

The half life of tebuthiuron in soil is estimated to be 12 to 15 months; this is longer in areas with lower moisture and in soils with high levels of organic matter (WSSA 1989). Tebuthiuron residues were detected 11 years after application on rangeland in semi-arid soils (Johnsen and Morton 1989). Microbial degradation through demethylation is the major mode of disappearance from soil (WSSA 1989).

9.2 METHODS FOR ASSESSMENT OF SOIL STERILANT AFFECTED SITES

9.2.1 Soil Sampling

The purpose of soil sampling is to obtain information on the type, the amount, and the depth of herbicide contamination. Soil sampling is also required to determine soil physical and chemical characterstics. The analysis is only as good as the soil sampling.

9.2.1.1 Control Samples. When trying to determine whether soil quality has been affected a control sample should be collected. It should be taken from a non-impacted site near the sterilant affected site where topography, soil type and soil moisture levels are similar. Down-slope or down-wind sites should be avoided.

9.2.1.2 Extreme Areas. Areas of extreme contamination, if evident, should be sampled separately to help identify "hot" spots. Do not sample wet areas or border areas.

9.2.1.3 Sampling Design. The selection of sampling sites will depend on the size and shape of the affected area, the uniformity of topography, soil type, soil moisture levels, and damage to the vegetation. Generally, sampling will be some compromise between the minimum desired for accuracy and that required for economy (Cline 1944). The best sampling designs are based on the random selection of sampling points. Alternatively, a systematic sampling approach may be used (IVMAA 1987; Pledger 1980).

1. Random Path Method (Figure 11). This procedure is the easiest. Draw a diagram of the site before sampling, then mark the sampling points. Pace out each subsequent sampling point making sure to match the direction and number of paces previously identified on the map. The direction of sampling through the plot should be varied in such a way that it covers a representative area of the plot.
2. Zig-Zag Pattern (Figure 12). Draw a diagram of the sample area, then mark the sampling points. Take samples in a zig-zag pattern throughout the area. This is a more rigid system of sampling, but it is easier to return to the original sampling points.
3. Grid System (Figure 13). This method is more systematic than the other approaches. A diagram should be drawn before starting to collect samples. All sample sites are at regular intervals from each other. The most suitable grid size depends on the number of points to be sampled. The grid should cover the entire area to be represented, and one random sample taken from within each unit. This technique ensures thorough coverage of the entire area.

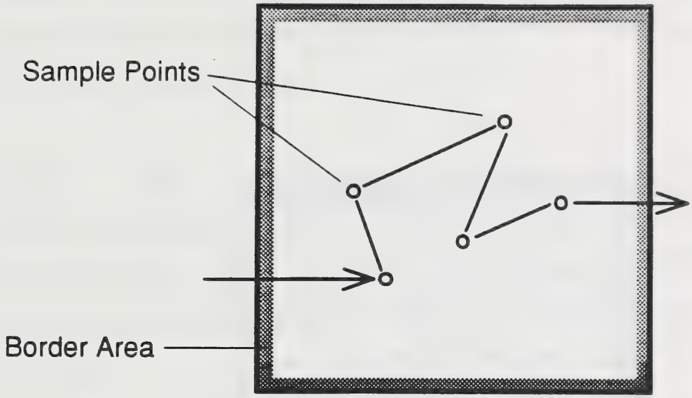

Figure 11. Random path soil sampling method.

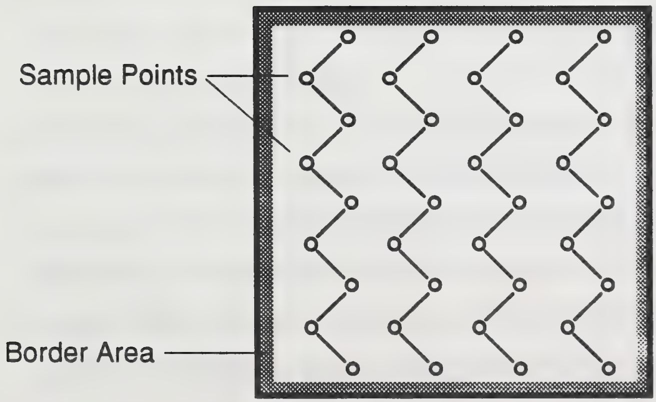

Figure 12. Zig-zag soil sampling method.

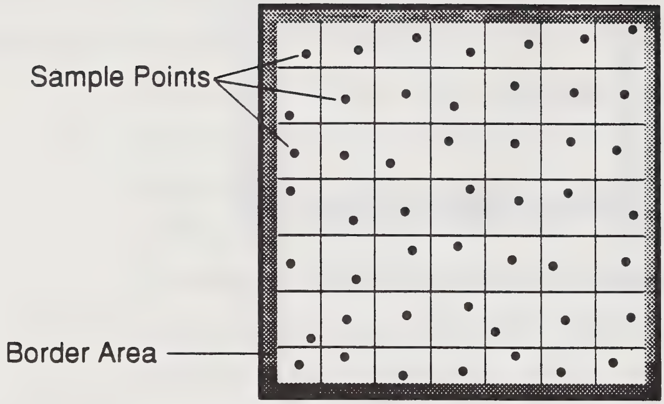

Figure 13. Grid system soil sampling method.

9.2.1.4 Vertical Subdivision. Soils are sampled by horizons (A, B, C, etc.) or by fixed increments (5, 10, 15 cm, etc.). In general, when sampling for sterilants, samples should be taken to a depth of 45 cm. A 15 cm increment is often used. Ideally, it is desirable to sample in smaller increments to provide better information on the location of the herbicide residues in the soil. However, cost encourages the use of 15 cm increments. Further information is needed to investigate the benefits of the more intense sampling versus the added cost. Note that if more than one sampling depth is used, each depth must be collected in a separate container. Sampling to the 45 cm depth can be difficult, but it is recommended because many plants root to this depth, and

herbicides can move up and contaminate reclaimed soil in the higher horizons (IVMAA 1987). Furthermore, if significant contamination is found in the 30 cm to 45 cm increment, it is recommended that the area should be re-sampled to a greater depth.

9.2.1.5 Safety. The area should be mapped for underground lines and pipes before proceeding with sampling. When working on an oil and gas lease the company's safety policy should be known. Most companies require a work permit, and that hard hats, safety boots, and safety glasses are worn while on the lease.

9.2.1.6 Number of Samples. The number of samples to be taken depends on the soil type, size and depth of the affected area, the variability in sterilant levels, and other potential contaminants. Two is the minimum number of samples that allows statistical evaluation of the data. Where the variability is high, the number of samples should increase to reduce sampling error (Webster and Oliver 1990). At least one control (off-site) sample must be taken.

9.2.1.7 Composite Samples. A substantial saving can result if laboratory analyses are performed on a composite of the samples rather than on the individual samples. A composite sample can be made up of any number of sub-samples and gives an average concentration from the sampled area. The Field Manual for Rehabilitating Soils Affected by Residual Herbicides, Third Edition (IVMAA 1987) suggests that between 10 to 20 samples are taken to form a single composite sample. No guidelines are given for choosing sample numbers to represent different areas. Sherma et al. (1979) suggests that a total of 49 cores be collected from a 0.1 ha area to form a composite sample. This

would provide intense sampling, and perhaps be more suited to research purposes.

If there is great variation in the area (e.g., in sterilant concentration or in soil type), the area should be divided into more homogeneous units. A composite of samples from two distinctly different areas is not representative of either area (Miller and Donahue 1990). Composite samples yield averages, and a reclamation plan based on averages may lead to problems in areas with a wide variability of contaminant concentrations.

The sub-samples should be thoroughly mixed to form one composite sample. The laboratory analyses are performed on the whole composite sample or on a sub-sample of the composite (Petersen and Calvin 1986). It is imperative to obtain a homogeneous sub-sample by breaking up the large clumps and thoroughly mixing the sub-samples in a suitable manner.

9.2.1.8 Sampling Equipment. The basic sampling equipment required includes: soil probe, auger, tube or shovel, bucket, plastic bags, tags, indelible marking pen, and a knife. It is important to keep all sampling equipment as clean and free of contamination as possible (IVMAA 1987). To avoid contamination, take samples from areas first where the least contamination is expected. Take the control sample first. Herbicide concentrations are determined at the part per million (ppm) and part per billion (ppb) levels. When working with these minuscule amounts keep in mind how easily samples can become contaminated (IVMAA 1987).

When choosing sampling equipment select items that cause the least soil mixing. A core sampler is best. Of the several soil sampling augers the ‘Dutch-type’ is probably the best because it minimizes soil mixing and is suitable for a wide range of soil types and conditions (IVMAA 1987). A

shovel can also be used; however it is not suitable for deeper depths. Whenever considerable leaching may have occurred shovels are not a suitable option.

Two points of caution in using sampling equipment (Norwest Labs N.D.):

1. On dry loose soil, the auger type samplers might yield unrepresentative samples by creating a funnel around the auger, allowing more soil to accumulate from near the surface.
2. In wet soil, the sampling equipment must be cleaned after each coring.

9.2.1.9 Timing of Sample Collection. Recent spills or herbicide applications, should be sampled as soon as possible after the event. Older sites, those treated over an extended period of time (e.g., decommissioned sites) have few limitations on time of sampling. Most importantly sampling should not be done when conditions are extreme, such as after a major rainfall (IVMAA 1987). Also, it should be kept in mind that soil samples are collected more easily when the soil is slightly moist.

9.2.1.10 Sample Identification and Lab Submission. The sample bags should be properly labelled for identification. Keep a master sheet outlining who is doing the sampling, map of the affected area, sample location, depth, properties to be analyzed and background information.

The samples should be sent to the laboratory immediately, or they should be kept in a cooler at 4°C. Changes occur quickly in the chemistry of soil, particularly when it is wet. If it is known that a sample contains high

rates of herbicide (industrial rates) the laboratory should be informed. This will prevent unnecessary contamination of the laboratory equipment.

9.2.2 Methods of Herbicide Residue Analyses

Both chemical assays and plant bioassays are used in residue analysis. The use of one method should not preclude the use of the other, and in fact, they are not substitutes for each other (Dowler 1969).

9.2.2.1 Chemical Assay Methods. Chemical assays methods are used to identify the kind and amount of herbicide in the soil. They cannot be used to determine phytotoxicity. This is particularly true in soils where the sterilant is bound to the soil colloids and is unavailable to the plant. Results can usually be obtained within a short period of time. Chemical assays are costly, and they involve complicated procedures and expensive equipment. They must be performed in a specialized laboratory. The laboratories in Alberta that provide soil sterilant analyses are listed in Appendix 9.3.

9.2.2.2 Plant Bioassays. A plant bioassay is a useful tool for determining the degree of phytotoxicity of the herbicide in soil when the identity of herbicide is known (Horowitz 1975). An appropriate plant species is used. Two basic assumptions of bioassays are: the selected plant will show an injury response in proportion to herbicide concentration, and the responses obtained are reproducible (Hurle 1977; Lavy and Santelmann 1986).

There are a number of advantages of using plant bioassays for herbicide residue detection. These include:

1. Many bioassay methods are highly sensitive and in some cases, they can also be more sensitive than analytical methods (Dowler

1969; Lavy and Santelmann 1986). For example, bioassay methods for chlorsulfuron and picloram are more sensitive than chemical analyses (M.P. Sharma unpublished results).

2. Bioassays measure the amount of biologically active herbicide in a soil sample at the time the test is conducted. Therefore when using bioassays one is assured that the phytotoxic activity of the herbicide is being measured (Dowler 1969; Lavy and Santelmann 1986).
3. Bioassay procedures are usually more economical, less difficult to perform, and do not require as much expensive equipment as chemical analysis. Once standard conditions have been set, the bioassay can be a reliable and sensitive procedure (Lavy and Santelmann 1986).
4. Bioassays are a valuable tool in the evaluation of herbicide behaviour in the soil when chemical methods are not available (Dowler 1969).

Plant bioassays have some limitations which include:

1. Whole plant bioassays generally require 3 to 4 weeks (Behrens 1970).
2. The total amount of herbicide in the sample is not measured.
3. Bioassays do not furnish conclusive data for the identification of the herbicide (Dowler 1969).
4. There can be species and individual plant variation in susceptibility to a given herbicide (Lavy and Santelmann 1986).

5. Herbicides become increasingly unavailable to plants over time and field results can not be duplicated exactly when comparing soils with dose response curve information (Behrens 1970; Lavy and Santelmann 1986).
6. There is a critical threshold level for each soil-herbicide-plant species combination; decreasing the plant density will result in greater plant injury; increasing the plant density will result in less plant injury (Lavy and Santelmann 1986).

9.2.2.3 Plant Bioassay Procedure. Determine the plant species sensitive to the herbicide. The species chosen must show a gradual increase in susceptibility with increasing herbicide concentration. A list of suitable plant species for herbicide bioassays is provided in Table 2.

Approximately 0.5 kg or more soil is used to perform plant bioassays. The soil is stored in a cool place until required; when moist soil samples are stored in a warm place, the herbicide residue can be degraded. If the soil is wet, spread it out and allow it to air-dry so it can be worked readily. An untreated soil sample should be gathered at the same time to be used as a control. Obtain the control soil from a similar site that has not been treated with herbicide.

Each soil should be well mixed and sieved to less than 2 mm. Do not pulverize. If the soil sample is rich in clay, add some sand. Do not add peat moss, sandy soil or vermiculite. Three pots each of contaminated and control soil are used so that variability in plant growth is accounted for. Half-litre or one-litre pots are suitable for growing the plants. Plug all drainage holes in the bottom of the pots, otherwise, the herbicide residues can be leached (Qureshi 1987).

Table 2. Selection of Plant Species for Herbicide Bioassay

Plants	ATRAZINE	BROMACIL	DIURON	CHLORSULFURON	PICLORAM
Alfalfa	S	S	S	VS	S
Faba Bean	MS	S	S	S	VS
Barley	S	S	S	T	MT
Beet	VS	S	S	VS	S
Corn	T	S	S	S	MT
Cucumber	VS	S	S	S	S
Green Foxtail	S	S	S	MT	T
Lettuce	S	S	S	S	MT
Mustard/ Canola	S	S	S	S	T
Oat	VS	S	S	T	T
Pumpkin	S	S	S	S	S
Rye Grass	U	S	S	T	T
Sunflower	U	S	S	S	VS
Wheat	S	S	S	T	MT
Wild Oat	MS	S	S	T	MT
Water-melon	U	S	S	S	S
Sugar Beet	S	S	S	VS	S
Tomato	S	S	S	S	VS
Wild Mustard	S	S	S	S	T
Lentils	U	S	S	VS	VS

VS = very susceptible S = susceptible MS = moderately susceptible MT = moderately tolerant T = tolerant U = unknown
Adapted from the original table in Qureshi (1987).

Seed the selected plant species, about 8 to 10 seeds per pot, 1 cm deep. The number of seeds varies with seed size. Wet the soil but do not saturate. Seed only one plant species per pot and label the pot. Allow the plants to grow 3 to 4 weeks (at least to the four-leaf stage). Keep the pots moist, but do not overwater. To avoid contamination between samples keep the pots well separated and avoid splashing while watering. Thin pots to a uniform number of plants after emergence if overcrowding becomes a problem.

Plant growth is directly influenced by environmental conditions, such as light, temperature, available nutrients, amount of water and method of adding it, and relative humidity. Variation in these factors can affect reproducibility of results; environmental and edaphic factors should be controlled as much as possible. If growth chambers or greenhouses are not available, place the containers in a warm, bright part of the building, preferably near a south-facing window.

Injury symptoms usually appear 10 to 20 days after plant emergence; however, if room temperature is below 21°C, it may take longer. Plant injury usually occurs in the form of wilting, chlorosis, leaf cupping, stem twisting, and necrosis, first on older tissue and then progressing to the newer growth (Sharma 1986).

At the conclusion of the bioassay period, the plants are first visually assessed for symptoms of herbicide toxicity (0 = complete death, 9 = complete tolerance). The plants are then harvested at soil level and fresh weights are measured immediately. The dry weight is measured by drying the vegetative portion in a forced air oven at 120°C for 24 hours.

9.3 PRIVATE LABORATORIES FOR HERBICIDE ANALYSIS

i. A & L Mid West Laboratories (Canada) Ltd.
2443 - 42 Avenue N.E.
Calgary, Alberta
T2E 8A3

(403) 250-3317

ii. AGAT Laboratories
International Headquarters
3801 - 21 Street N.E.
Calgary, Alberta
T2E 6T5

(403) 291-2428

iii. Chemex Labs Alberta Inc.
2021 - 41 Avenue N.E.
Calgary, Alberta
T3E 6P2

(403) 291-3077

iv. Core Laboratories
Western Atlas Canada Ltd.
1540 - 25 th Avenue N.E.
Calgary, Alberta
T2E 7R2

(403) 250-4000

v. Enviro-Test Laboratories
9936 - 67 Avenue
Edmonton, Alberta
T6E 0P5

(403) 434-9509

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RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes (one at Caw Creek Ridge and two at Cadomin). Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. $10.00**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

4. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

5. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

6. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

7. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

8. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

9. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

10. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

11. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

12. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

13. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

14. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

15. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

16. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

17. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

18. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. No longer available.**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

19. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

20. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

21. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

22. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

23. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

24. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

25. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

26. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

27. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

28. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

29. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

30. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. No longer available.**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

31. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

32. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. No longer available.**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

33. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

34. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

36. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

37. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

38. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

39. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

40. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. $10.00**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

41. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

42. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

43. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. $10.00**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

44. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

45. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

46. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. $10.00**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

47. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

48. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

49. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

50. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. $10.00**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

51. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. No longer available.**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

52. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

53. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

54. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

55. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. No longer available.**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

56. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

57. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. No longer available.**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

58. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. $10.00**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

59. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. $10.00**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

60. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

61. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. No longer available.**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

62. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

63. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

64. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. S.R. Moran, T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.

65. **RRTAC 90-5: Review of the Effects of Storage on Topsoil Quality. Thurber Consultants Ltd., Land Resources Network Ltd., and Norwest Soil Research Ltd. 116 pp. $10.00**

The international literature was reviewed to determine the potential effects of storage on topsoil quality. Conclusions from the review indicated that storage does not appear to have any severe and longterm effects on topsoil quality. Chemical changes may be rectified with the use of fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with the stripping and respreading operations. Soil biotic populations appear to revert to pre-disturbance levels of activity within acceptable timeframes. Broad, shallow storage piles that are seeded to acceptable grass and legume species are recommended; agrochemical use should be carefully controlled to ensure soil biota are not destroyed.

66. **RRTAC 90-6: Proceedings of the Industry/Government Three-Lift Soils Handling Workshop. Deloitte & Touche. 168 pp. $10.00**

This report documents the results of a two-day workshop on the issue of three-lift soils handling for pipelines. The workshop was organized and funded by RRTAC, the Canadian Petroleum Association and the Independent Petroleum Association of Canada. Day one focused on presentation of government and industry views on the criteria for three-lift, the rationale and field data in support of three- and two-lift procedures, and an examination of the various soil handling methods in use. During day two, five working groups discussed four issues: alternatives to three-lift; interim criteria and suggested revisions; research needs; definitions of terms. The results of the workshop are being used by a government/industry committee to revise soils handling criteria for pipelines.

67. **RRTAC 90-7: Reclamation of Disturbed Alpine Lands: A Literature Review. Hardy BBT Limited. 209 pp. $10.00**

This review covers current information from North American sources on measures needed to reclaim alpine disturbances. The review provides information on pertinent Acts and regulations with respect to development and environmental protection of alpine areas. It also discusses: alpine environmental conditions; current disturbances to alpine areas; reclamation planning; site and surface preparation; revegetation; and, fertilization. The report also provides a list of research and information needs for alpine reclamation in Alberta.

68. **RRTAC 90-8: Plains Hydrology and Reclamation Project: Summary Report. S.R. Moran, M.R. Trudell, T.M. Macyk and D.B. Cheel. 105 pp. $10.00**

This report summarizes a 10-year study on the interactions of groundwater, soils and geology as they affect successful reclamation of surface coal mines in the plains of Alberta. The report covers: Characterization of the Battle River and Wabamun study areas; Properties of reclaimed materials and landscapes; Impacts of mining and reclamation on post-mining land use; and, Implications for reclamation practice and regulation. This project has led to the publication of 18 RRTAC reports and 22 papers in conference proceedings and referred journals.

69. **RRTAC 90-9: Literature Review on the Disposal of Drilling Waste Solids. Monenco Consultants Limited. 83 pp. $5.00**

This report reviews the literature on, and government and industry experience with, burial of drilling waste solids in an Alberta context. The review covers current regulations in Alberta, other provinces, various states in the US and other countries. Definitions of various types of burial are provided, as well as brief summaries of other possible disposal methods. Environmental concerns with the various options are presented as well as limited information on costs and monitoring of burial sites. The main conclusion of the work is that burial is still a viable option for some waste types but that each site and waste type must be evaluated on its own merits.

70. **RRTAC 90-10: Potential Contamination of Shallow Aquifers by Surface Mining of Coal. M.R. Trudell, S.R. Moran and T.M. Macyk. 75 pp. $5.00**

This report presents the results of a field investigation of the movement of salinized groundwater from a mined and reclaimed coal mine near Forestburg into an adjacent unmined area. The movement is considered to be an unusual occurrence resulting from a combination of a hydraulic head that is higher in the mined area than in the adjacent coal aquifer, and the presence of a thin surficial sand aquifer adjacent to the mine. The high hydraulic head results from deep ponds in the reclaimed landscape that recharge the base of the spoil.

71. **RRTAC 91-1: Reclamation Research Annual Report - 1990. Reclamation Research Technical Advisory Committee. 69 pp. $5.00**

This annual report describes the expenditure of $499 612 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program. The report lists the 70 research reports published under the program.

72. **RRTAC 91-2: Winter Soil Evaluation and Mapping for Regulated Pipelines. A.G. Twardy. 43 pp. $5.00**

Where possible, summer soil evaluations are preferred for pipelines. However, when winter soil evaluations must be done, this report lays out the constraints and requirements for obtaining the best possible information. Specific recommendations include: restricting evaluations to the time of day with the best light conditions; use of core- or auger-equipped drill-trucks; increased frequency of site inspections and soil analyses; and, hiring a well-qualified pedologist. The province's soils are divided into four classes, based on their difficulty of evaluation in winter: slight (most soils); moderate; high; and, severe (salt-affected soils in the Brown and Dark Brown Soil Zones).

73. **RRTAC 91-3: A User Guide to Pit and Quarry Reclamation in Alberta. J.E. Green, T.D. Van Egmond, C. Wylie, I. Jones, L. Knapik and L.R. Paterson. 151 pp. $10.00**

Sand and gravel pits or quarries are usually reclaimed to the original land use, especially if that was better quality agricultural or forested land. However, there are times when alternative land uses are possible. This report outlines some of the alternate land uses for reclaimed sand and gravel pits or quarries, including: agriculture, forestry, wildlife habitat, fish habitat, recreation, and residential and industrial use. The report provides a general introduction to the industry and to the reclamation process, and then outlines some of the factors to consider in selecting a land use and the methods for reclamation. The report is not a detailed guide to reclamation; it is intended to help an operator determine if a land use would be suitable and to guide him or her to other sources of information.

74. **RRTAC 91-4: Soil Physical Properties in Reclamation. M.A. Naeth, D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 204 pp. $10.00**

This report provides information from the literature and Alberta sources on a variety of soil physical properties that can be measured on reclaimed sites. Each property is explained, measurement methods, problems, level of accuracy and common soil values are presented, and methods of dealing with the property (prevention, alleviation) are discussed. The report also contains the results of a workshop held to discuss soil physical properties and the state-of-the-art in Alberta.

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